

## **Ocean Basin Impact of Ambient Noise on Marine Mammal Detectability, Distribution, and Acoustic Communication - YIP**

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### **LONG-TERM GOALS**

The ultimate goal of this research is to enhance the understanding of global ocean noise and how variability in sound level impacts marine mammal acoustic communication and detectability. How short term variability and long term changes of ocean basin acoustics impact signal detection will be considered by examining 1) the variability in low-frequency ocean sound levels and sources, and 2) the relationship of sound variability on signal detections as it relates to marine mammal active acoustic space and acoustic communication. This work increases the spatial range and time scale of prior studies conducted at a local or regional scale. The comparison of acoustic time series from different ocean basins provides a synoptic perspective by which to observe and monitor ocean noise on multiple times scales in both hemispheres as economic and climate conditions change. Quantified changes in the acoustic environment can then be applied to the investigation of ocean noise issues related to general signal detection tasks, as well as marine mammal acoustic communication and impacts.

### **OBJECTIVES**

The growing concern that ambient ocean sound levels are increasing and could impact signal detection of important acoustic signals being used by animals for communication and by humans for military and mitigation purposes will be addressed. The overall goal of the study is to gain a better understanding of how low frequency sound levels vary over space and time. This knowledge will then be related to the range over which marine mammal vocalizations can be detected over different time scales and seasons. Over a decade of passive acoustic time series from the Indian and Pacific Oceans will be used to address the following project objectives:

- 1. Determine the major sources (or drivers) of variation in low frequency ambient sound levels on a regional and ocean basin scale.**
  - A. What are the regional source contributions to low frequency ambient sound levels?
  - B. Is there variation in source characteristics of the major low frequency source components over space and time?
  - C. Is low frequency sound level uniformly increasing on a global scale?
- 2. Investigate the impacts of variation in low frequency ambient sound levels on signal detection range, marine mammal communication, and distribution.**
  - A. How does species specific detection range (acoustic active space) vary on a daily, weekly, monthly, and yearly time scale?

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- B. Are low-frequency vocalization detections related to changes in ambient sound level?
- C. Do marine mammals exhibit any changes in calling behavior to compensate for noise?

## APPROACH

The originally proposed effort was a comparative study of passive acoustic time series from Comprehensive Test Ban Treaty Organization (CTBTO) locations in the Indian (H08) and Pacific (H11) Oceans over the past decade (Figure 1, Table 1). An additional site at Ascension Island (H10) in the Atlantic Ocean was added this year because it provides an additional southern hemisphere site for comparing noise trends to the Wake Island site in the northern hemisphere (Figure 1, Table 1). CTBTO monitoring stations consist of two sets of three omni-directional hydrophones (0.002-125 Hz) on opposite sides of an island. Two triads of hydrophones eliminate the acoustic shadow created by the island to ensure full area coverage of an ocean basin. The hydrophones are located in the SOFAR channel at a depth of 600 to 1200 m, depending on location. The hydrophones are cabled to land 50-100 km away and connected to shore stations for data transmission. The sites are under the national control of the countries to which the hydrophones are cabled and data is available via AFTAC/US NDC (Air Force Tactical Applications Center/ US National Data Center) for US citizens.

Individual datasets are calibrated to absolute sound pressure levels (SPL) in standard SI units, removing site-specific hydrophone response. Comparisons between high and low latitude sound levels are made by comparing the time series from elements on opposite sides of each island location. Many of the acoustic signals have been well characterized for various species of marine mammals, physical events, and anthropogenic sources such as seismic, allowing for development of automated spectrogram correlation detectors that will be run on long batches of recorded data to detect the presence of sounds produced by particular species or sources (i.e. Mellinger & Clark, 2000, 2006). These automated detection methods make it practical to survey the large dataset proposed in this study which would be prohibitively time consuming for a manual search.

The cornerstone of project success is the appropriate time series analyses and comparisons over time at a single location and across locations. While there is great scientific merit in quantifying the acoustic relationship between physical and biological parameters of the marine ecosystem, the integration of the acoustic datasets with ancillary data sets further enhances the value of the research by ensuring the appropriate comparisons are made between locations and over time at the same location. Remotely sensed chlorophyll concentration, photosynthetically available radiation, and sea surface temperature are being modeled for the targeted ocean regions. Historical vessel data and movements were purchased through Lloyd's Marine Intelligence Unit (MIU). The database extends back to 1997, which is appropriate for obtaining shipping data over the same time periods and scales of the acoustic data and other ancillary datasets.

An initial key question that must be addressed when interpreting passively collected ambient noise is: "What is the most appropriate unit of analysis or size window over which the data is being examined?" Long-term analyses of ambient sound levels require particular care in selecting the unit of analysis because sources contribute to the ambient sound level on different time and spatial scales. The optimal unit of analysis and sub-sampling interval should capture the true variation of the system while excluding redundant data in order to minimize processing time (Curtis et al., 1999). Data processing in previous ambient sound studies range from using all data acquired with continuously recording systems to sparsely subsampled data from remotely deployed autonomous systems. There are currently no standards for sub-sampling intervals, averaging window lengths, or other parameters related to the analysis of long-term ambient noise data, which is necessary in order to compare and interpret data sets recorded from different systems, in different places, and at different times. The unit of analyses that have been previously used in ambient sound studies was either arbitrarily selected,

defined by system limitations, or selected based on criteria other than results of statistical tests exploring the data variability. Hence, one of this year's project efforts focused on developing methods to identify the optimal unit of analysis for data from a single location (H08 in the Indian Ocean) by determining at what point sub-sampling of the ambient sound level caused a significant deviation from the actual sound level. Results of this effort will then be applied to the analysis of ambient sound data from the other two oceans, used in the development of mixed-models to identify significant drivers of ambient sound variability, and translated to calculations of detection ranges for defining the relationship of sound variability on signal detection as it relates to marine mammal active acoustic space and acoustic communication.

## **WORK COMPLETED**

Research efforts this past year focused on: 1) developing methods to identify the optimal unit of analysis for processing long-term acoustic time series, and 2) generating acoustic, shipping, and oceanographic time series needed to develop predictive models of ambient sound and signal detection ranges. Data from three different CTBTO sites have been downloaded from the AFTAC/US NDC to ARL Penn State. The site locations and data coverage are shown in Table 2. Data continues to be downloaded on a monthly basis to keep the database current. A quality control check was performed on the downloaded and decompressed data to verify proper decompression. Data decompressed at ARL PSU was compared to decompressed data available to the public. The two data streams matched in absolute levels which verified the accuracy of the decompression algorithms and application of the calibration curves obtained for each hydrophone.

In-depth analysis of the acoustic time series at Diego Garcia was completed to identify the point at which longer averaging windows and sub-sampling intervals result in a significant deviation from the actual sound levels and variation. Thirty second averages sub-sampled at intervals of 0.5, 1, 5, 30, and 60 minutes were analyzed for the full CTBTO spectrum and two 20-Hz bandwidths: 10-30 Hz and 85-105 Hz. The 10-30 Hz band was selected as representative of low frequency vocalizations from large whales (e.g. blue and fin whales). The 85-105 Hz band was selected as representative of the dominant frequencies of distant shipping. Autocorrelation analyses were also conducted on the decade time series from each island side at Diego Garcia.

Based on the results from Diego Garcia, time series of daily averages were calculated for all sites from the date of site inception to the summer of 2012. Soundscapes were also created as an alternative mode of presentation for comparing and contrasting sound level and variation across sites. Visual representations, or soundscapes, of the acoustic environment were created from data on each side of the island and for each season at each site. Soundscapes were generated by calculating and plotting the ratio of energy in the two targeted bandwidths.

Historical vessel data and quarterly movements from the Indian and Pacific Oceans were purchased from Lloyd's Marine Intelligence Unit (MIU) for the time period from 2002-mid 2011. Ship movements were reported from 48 and 38 countries, respectively for the Pacific and Indian Oceans. Data was categorized by deadweight tonnage for five vessel type categories.

The parsing of ocean regions into biogeochemical provinces allows for temporal variability of chlorophyll concentration, sea-surface temperature, and primary productivity to be identified that may otherwise be masked by dominant global phenomena. Several approaches to determine how to parse the satellite imagery data in biogeochemical provinces have been explored including both static and dynamic boundaries.

## RESULTS

Unit of analysis results from the Indian Ocean indicated that sub-sampling 30-sec time periods at intervals larger than 60 seconds for the full spectrum and 10-30 Hz band levels has the potential to bias overall sound levels. Sub-sampling intervals of 5 minutes or greater underestimate the true sound level when loud transient signals are not included in the sampling period but are present in the environment. Sub-sampling intervals of 5 minutes or greater also have the potential to overestimate the true sound level when loud transient signals are included in the sampling period more often than by chance, such as when the source is periodic and coincides with the sampling period. Analysis of the sub-sampling intervals for the 85-105 Hz band levels showed no significant differences between any sampling interval. Therefore, in order to represent the most realistic sound levels and variation across the full spectrum of frequencies, one minute means calculated sequentially over the time series and then averaged over the time period of interest was determined to be the optimal processing strategy for representing the true sound levels and variability, which was then applied to the analysis of times series from the other two oceans.

Recordings made off Wake Island in the Pacific Ocean were louder than the recordings made from islands in the Indian and Atlantic Oceans (Figures 2 and 3). The Pacific Ocean recordings showed very similar levels from recordings made on the north and south sides of the island. In contrast, both the Atlantic and Indian Oceans had higher levels of low frequency bandwidth sound in recordings made on the south side of the island (Figures 2 and 3). Soundscapes made from data recorded from the south island sensors in the Atlantic and Indian Ocean recordings were louder in both dimensions compared to the data recorded on the north side of the island. The overall trend observed from the three sites is that within each hemisphere, the sensors directed towards the poles have greater sound levels than those on the equator side of the island. Initial linear regression analyses indicated an approximate 3 dB increase in the 85-105 Hz band over a decade from the south side of Diego Garcia. An approximate 2 dB increase in the 10-30 Hz band and over the full spectrum was observed over the decade analyzed from Diego Garcia's south side for frequencies below 120 Hz. Sound levels recorded from the north side of the island showed less of an increase over the past decade: full spectrum – 1.5 dB increase, 10-30 Hz band – 0.4 dB increase, 85-105 Hz band – 0.75 dB increase.

Although recordings were most consistent in level and variability from the north and south side of Wake Island in the Pacific Ocean, this site showed the greatest seasonal variability of the three ocean island sites (Figures 2 and 4). In the Pacific, there was an increase in the 10-30 Hz band without a corresponding increase in the 85-105 Hz band in October 2008 (Figure 4C). This is most likely associated with the peak in migration of large whale species arriving in the tropics for the winter breeding season. The largest soundscape shift off Ascension Island in the Atlantic Ocean occurred in April 2008 (Figure 4B). This was an increase in both frequency dimensions most likely associated with an increase in shipping compounded by an increase in marine mammal vocalizations. The Indian Ocean location at Diego Garcia showed the least seasonal variability (Figure 4A). Sound levels around Diego Garcia appeared to be most variable in all seasons.

An examination of the relative contribution of different frequencies to the overall ambient sound level, variability, and periodicity has begun. A firm understanding of the relative frequency contributions and periodicities in the ambient sound will support identification and interpretation of source contributions. The contribution of the 10-30 Hz and 85-105 Hz band levels to the overall sound levels were different in magnitude between sites and between the north and south sides of the islands at Ascension Island and Diego Garcia (Figure 5). The largest difference in relative frequency contribution was observed between the north and south sides of Diego Garcia. This is most likely due to the placement of hydrophones on opposite sides of an underwater plateau. Differences in periodicity between frequency components were also observed (Figure 6). Periodicity at 30 Hz differed

temporally depending on which side of the island was being analyzed. While an acoustic correlation occurred in the north with a lag of approximately 350 days, the southern hydrophones showed a lag of 175 days at the same frequency. This indicates a delay of 6 months between the north and south. This difference could be caused by seasonal whale migrations or even recurring tropical storms that occur in the Indian Ocean (Branch et al., 2007; Piggot, 1964). The difference in acoustic periodicity between the northern and southern hydrophones demonstrates the importance of acoustical directionality in the analysis of ambient noise.

Progress made in generating supporting time series for the acoustic data include defining of oceanographic provinces and compiling vessel movement. Several approaches to defining biogeochemical provinces were considered. The Longhurst provinces were defined based on similar behavior in physical and ecological processes of large expanses of the ocean (Longhurst 1995, 2006). The provinces were defined primarily from *in situ* observations and expert interpretation and are static in time. There have been more recent attempts at defining provinces with the aid of satellite remote sensing imagery, allowing for dynamic boundaries. Moore et al. (2001) utilized a fuzzy logic approach to identify optically –distinct water types from remote sensed reflectance measurements. Oliver and Irwin (2008) utilized SST and normalized water-leaving radiance imagery to define dynamic provinces solely on physical parameters and statistical methodologies. Hardman-Mountford et al. (2008) also utilized satellite remote sensing imagery, but used only chlorophyll. IOCCG (2009) note that the dynamic province approaches have good persistence in time, thus the use of static rather than dynamic boundaries are appropriate. The most appropriate parsing approach for this project was determined to be the Longhurst provinces (Figure 7). The compilation of Lloyd's MIU vessel movement data across the Indian and Pacific Oceans indicate that vessel movements of all shipping classes are increasing (Figure 8).

## **IMPACT/APPLICATIONS**

Quantifying the relationship between factors affecting ocean sound variability and corresponding ecosystem response will illustrate the effectiveness of passive acoustic monitoring for tracking ocean use changes and provide critical information needed for predictive modeling of signal detection probability. The value of this study is that the statistical details of ambient noise are quantified over different temporal scales at an ocean basin level, thus extending knowledge gained from local and regional scale studies. Sound level statistics are a critical parameter set when describing noise and are fundamental to reducing the uncertainty of signal detection when applying the passive sonar equation. The integration of acoustic time series from different ocean basins will provide a synoptic perspective by which to monitor ocean noise in both hemispheres as economic and climate conditions change. The rapid economic growth of India and China is predicted to have a measurable impact on low frequency ambient sound and signal detectability through increased shipping. Results will support the development of mathematical models that predict ambient sound levels from economic growth patterns and shipping statistics. The application of the noise statistics to marine mammal detection and acoustic behavior will illustrate the value of understanding how economic, military, and other geo-political drivers influencing shipping, a dominant component of ocean ambient sound, can impact the marine ecosystem.

## **TRANSITIONS**

This project represents a transition from the acoustic characterization of local and regional areas to the characterization of ocean basins. Detailed knowledge of noise statistics and variation will contribute to reducing error associated with marine animal density estimates generated from passive acoustic datasets, signal detection and localization, and propagation models.

## RELATED PROJECTS

The current project is directly related to and collaborative with ONR Ocean Acoustics Award N00014-11-1-0039 to David Bradley titled “Ambient Noise Analysis from Selected CTBTO Hydroacoustic Sites”. Patterns and trends of ocean sound observed in this study will also be directly applicable to the International Quiet Ocean Experiment being developed by the Scientific Committee on Oceanic Research (SCOR) and the Sloan Foundation ([www.iqoe-2011.org](http://www.iqoe-2011.org)).

Data being processed and analyzed in this study from the Ascension Island location in the Atlantic is being combined with data from Holger Klinck (Oregon State University) to quantify ambient sound across the Atlantic from pole to pole. Data from the Arctic was collected by H. Klinck under Marine Mammal Commission, National Fish and Wildlife Foundation Grant No. 2010-0073-003 and the NOAA Vents Program. Antarctic data was also collected by H. Klinck under a Korea Polar Research Institute award.

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## PUBLICATIONS

- Miksis-Olds JL, Smith CM, Hawkins RS and Bradley DL. 2012. Seasonal soundscapes from three ocean basins: what is driving the differences? Conference Proceedings of the 11<sup>th</sup> European Conference on Underwater Acoustics 34: 1583- 1587. ISBN 978-1-906913-13-7.
- Hawkins RS, Miksis-Olds JL, Bradley DL and Smith CM. 2012. Periodicity in ambient noise and variation based on different temporal units of analysis. Conference Proceedings of the 11<sup>th</sup> European Conference on Underwater Acoustics 34: 1417- 1423. ISBN 978-1-906913-13-7. (First author is student of Miksis-Olds)
- Nichols SM, Bradley DL, Miksis-Olds JL and Smith CM. 2012. Are the world's oceans really that different? Conference Proceedings of the 11<sup>th</sup> European Conference on Underwater Acoustics 34: 338- 345. ISBN 978-1-906913-13-7.

## HONORS/AWARDS/PRIZES

Office of Naval Research Young Investigator Program (YIP) Award – 2011

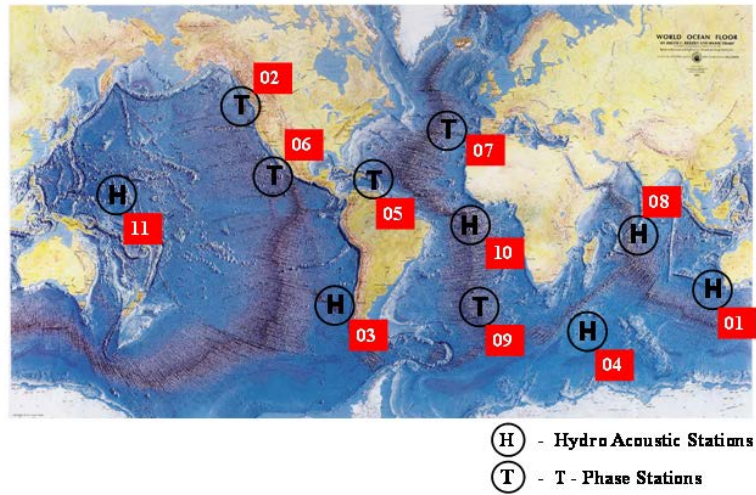
***Table 1. Acoustic sensor location summary. Latitude areas in parentheses under Latitude Region indicate acoustic focus of sensors on opposite sides of island.***

Site	Element	Acoustic Focus	System	Location	Latitude Region of Sensor	Major Oceanographic Process
HA08	N	Equatorial Indian	CTBTO	Diego Garcia, UK	Low	Equatorial Current
	S	Indian	CTBTO	Diego Garcia, UK	Low (Mid)	Equatorial Current
HA11	N	W Pacific	CTBTO	Wake Is., USA	Low (Mid)	N Equatorial Current
	S	Equatorial Pacific	CTBTO	Wake Is., USA	Low	N Equatorial Current
HA10	N	Equatorial Atlantic	CTBTO	Ascension Is., UK	Low	S Equatorial Current
	S	S Atlantic	CTBTO	Ascension Is., UK	Low (Mid)	S Equatorial Current

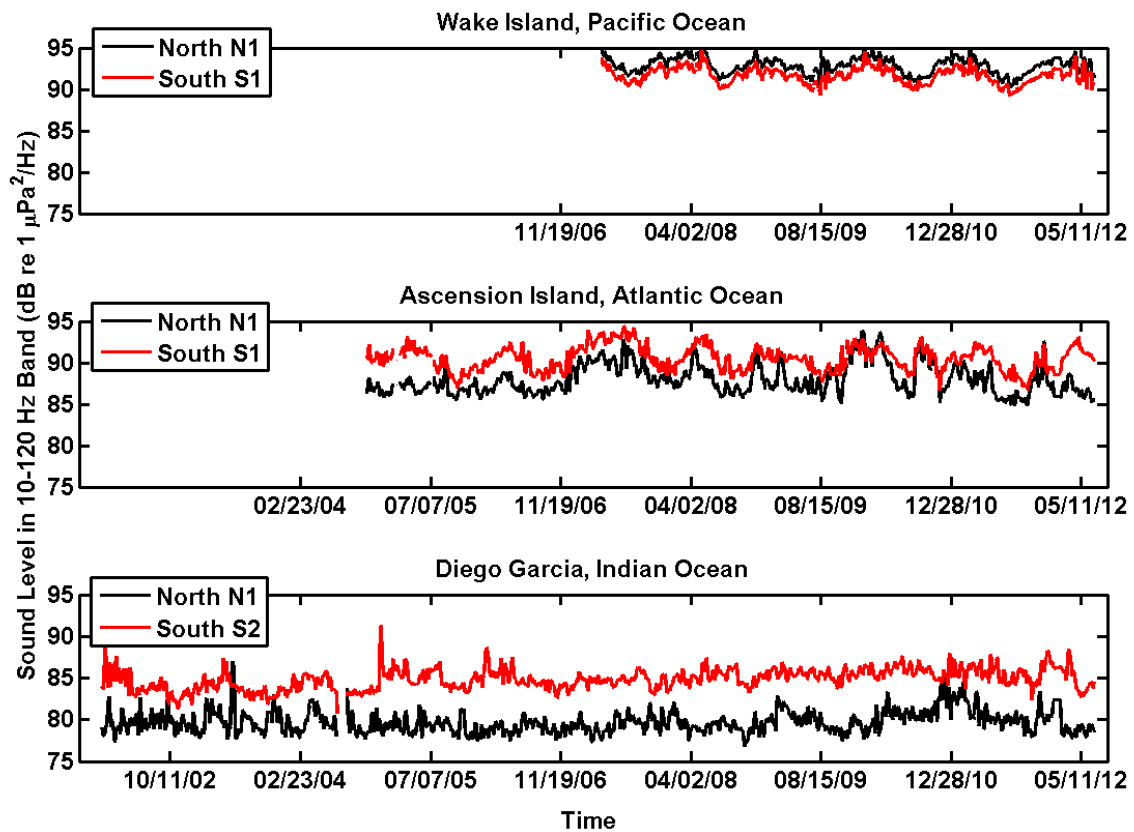
***Table 2. Data successfully downloaded and available to ARL Penn State.***

Site/Location	Start Day	Most Recent Download	# Missing Days	Total Days	Total Years
HA08/Diego Garcia	01/21/2002	07/08/2012	40	3782	10.4
HA10/Ascension Island	11/04/2004	07/08/2012	4	2800	7.7
HA11/Wake Island	04/25/2007	07/08/2012	5	1897	5.2

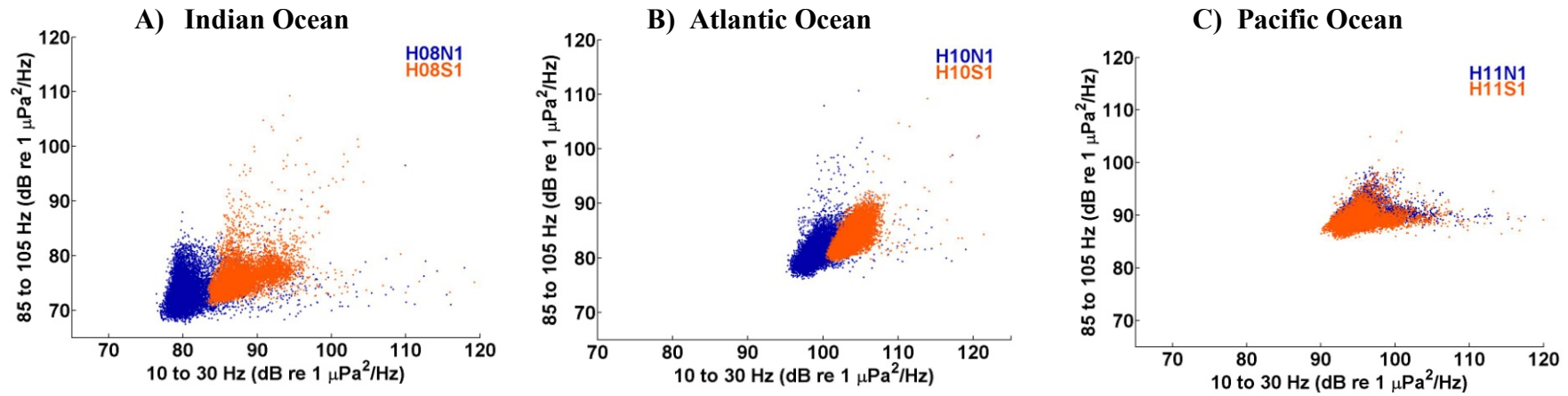




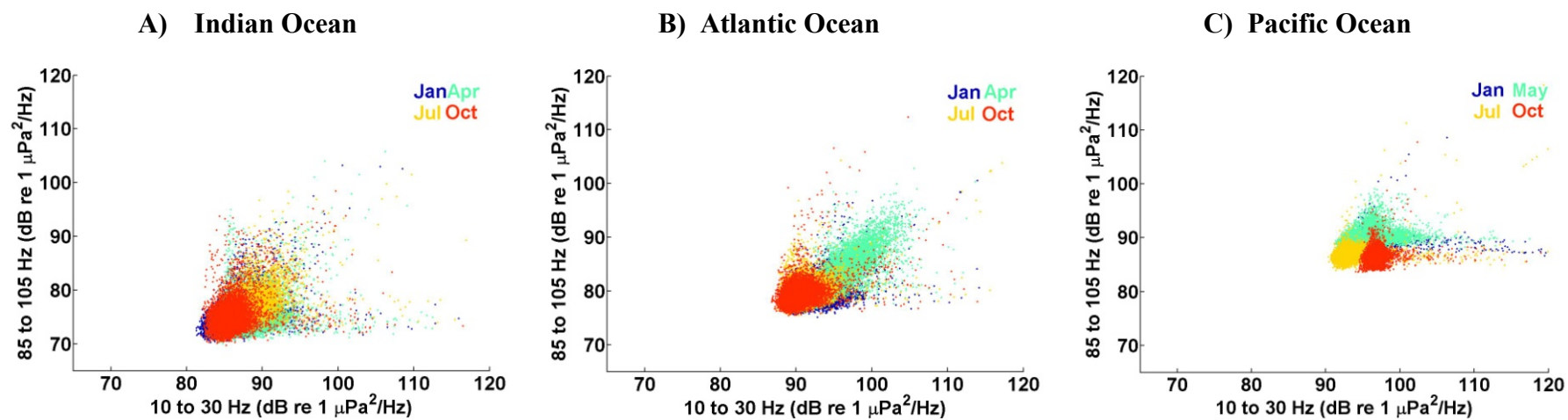
**Figure 1. Location of CTBTO Hydroacoustic Sites. *H* sites denote hydrophone sites, moored in the water column at sound channel depths. *T* sites denote seismic “T-phase” sensors. This project will use data from *H*08, *H*10, and *H*11.**



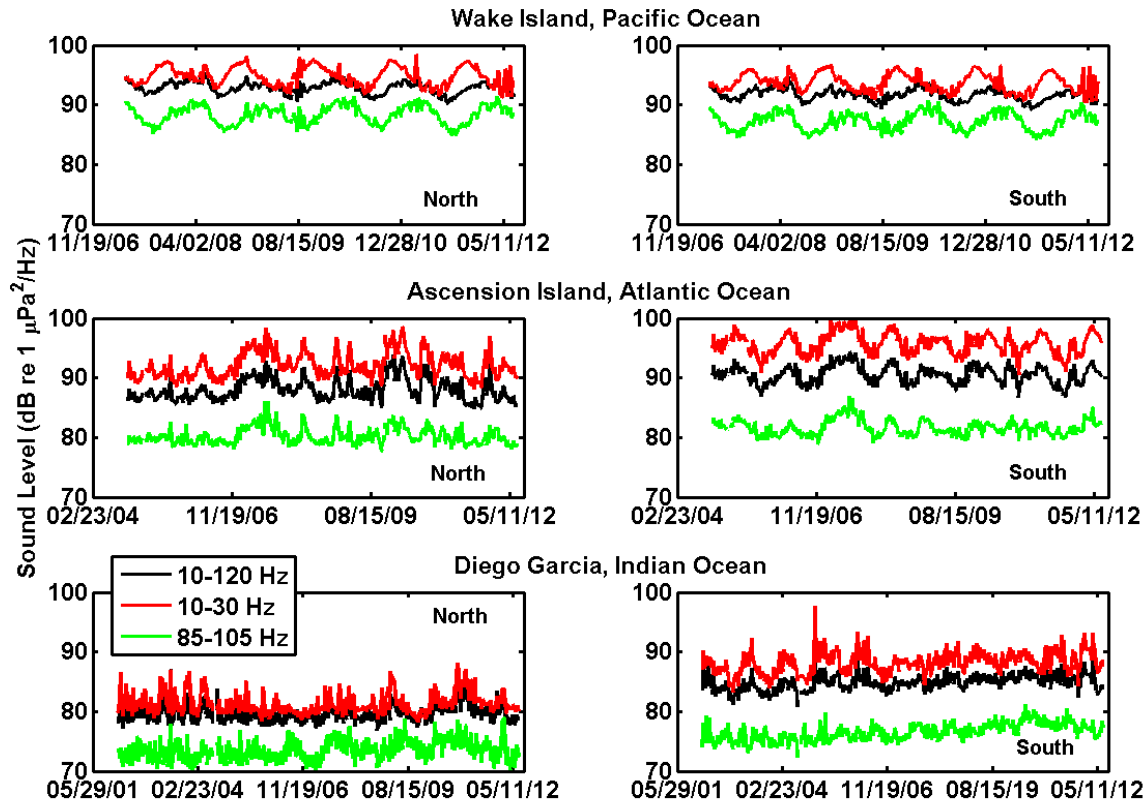
**Figure 2. Full time series of daily averages from both island sides at each ocean location. The data was smoothed with a 10 point moving average filter. The south sides of the island have higher sound levels for islands in the southern hemisphere (Diego Garcia and Ascension). Sound levels from the north side of the island were higher for the Wake Island location in the northern hemisphere.**



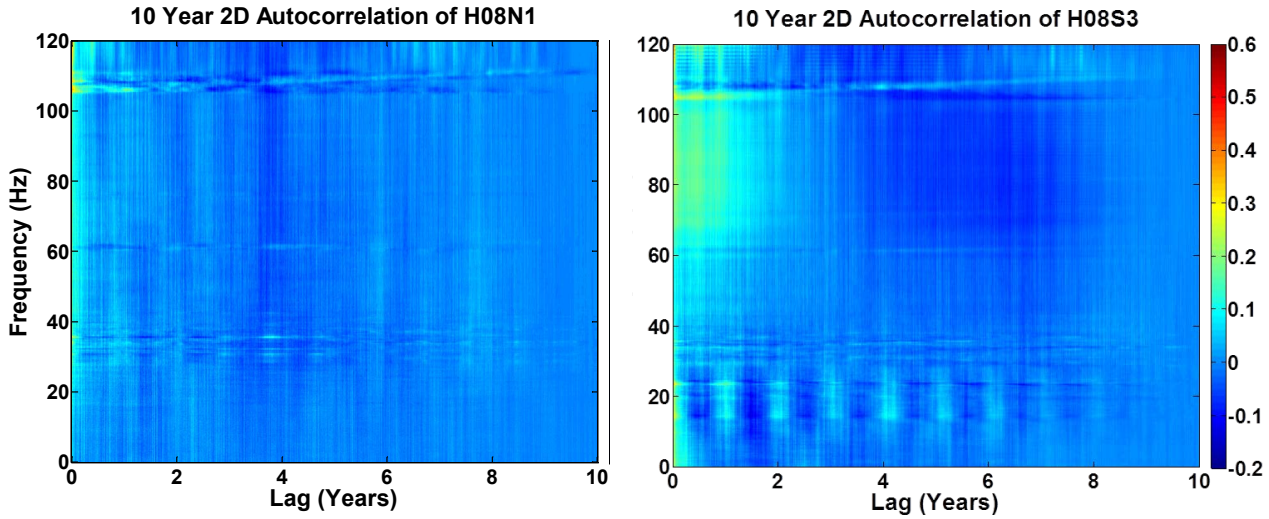
*Figure 3. Soundscapes made at each island location in the A) Indian, B) Atlantic, and C) Pacific Oceans. Each plot contains overlaid soundscapes from opposite sides of the island in May 2008. Legend labels correspond to the numerical site location and sensor number (N1= North of island, sensor 1; S1= South of island, sensor 1).*



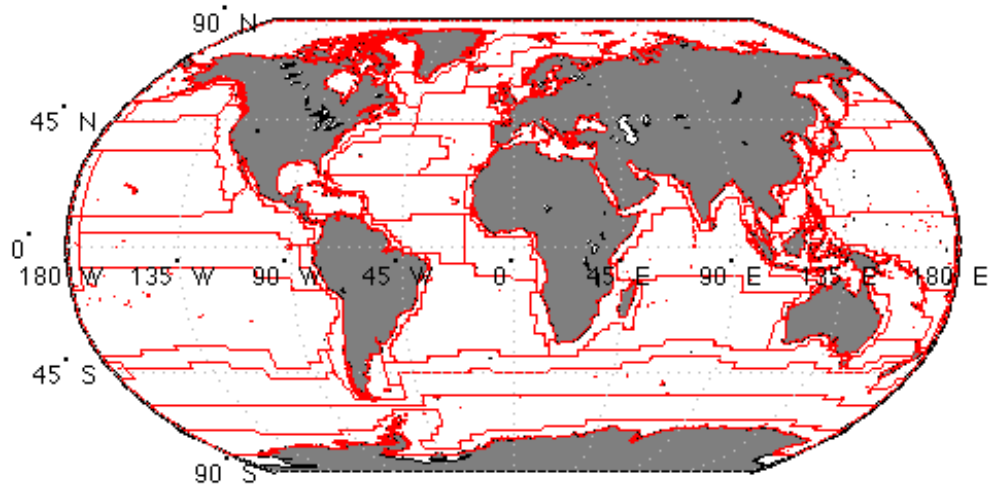
*Figure 4. Seasonal soundscapes made from the north side of each island location in 2008 in the A) Indian, B) Atlantic, and C) Pacific Oceans.*



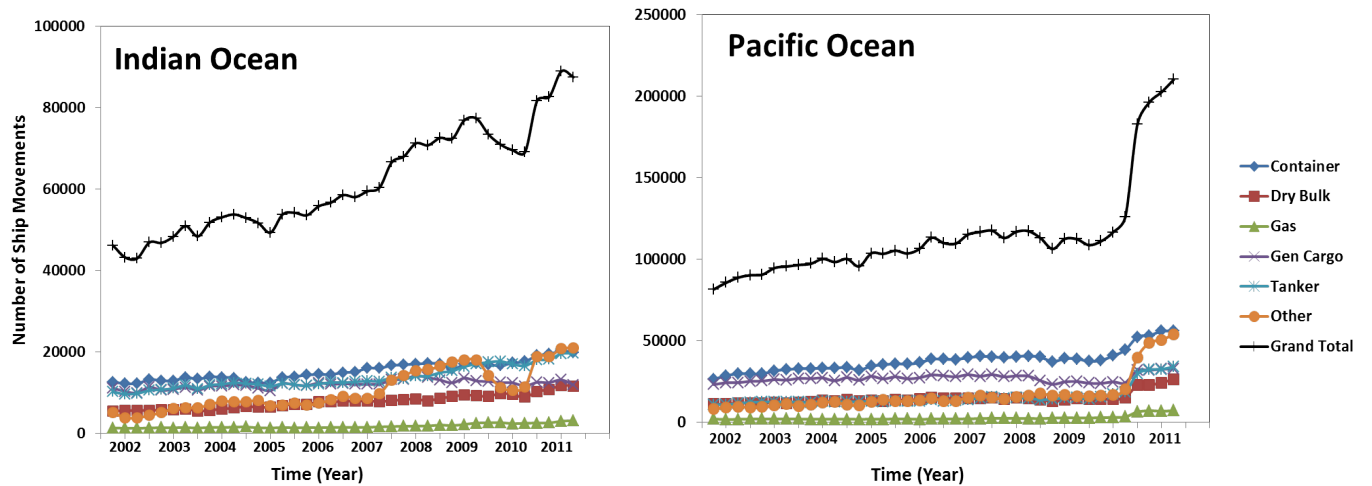
**Figure 5.** Full spectrum and selected band level time series from each ocean location.



**Figure 6.** Ten year, full spectrum autocorrelation from the north (A) and south (B) side of Diego Garcia. (A) Correlations are present at 110 Hz, 60 Hz and 30-40 Hz. The 30-40 Hz correlation coincides with a 1 year periodicity indicating that the source is contributing to the increase in sound level on a seasonal basis. (B) Correlations are present at 110 Hz and 30-40 Hz with an added correlation at 10-30 Hz. The 10-30 Hz periodicity is one year. The 30-40 Hz periodicity is also 1 year, however the lag is offset by  $\frac{1}{2}$  year compared with the northern hydrophone. The difference in time between the correlation of the northern and southern hydrophones may indicate a relocating sound source, which could be caused by the migration of marine mammals.



**Figure 7.** Example of the Longhurst biogeochemical province partition (VLIZ, 2009).



**Figure 8.** Quarterly vessel movements broken down by vessel type in the Indian and Pacific Oceans. The largest changes were observed in the Other categories composed of all other vessel types not categorized into the other 5 vessel type categories.